WATER CIRCULATION PATTERN FROM SEA SURFACE CURRENT AND CHLOROPHYLL-A DERIVED USING SATELLITE DATA IN THE SOUTH CHINA SEA

Mohd Ibrahim Seeni Mohd, Samsudin Ahmad, Fung Fook Wah and Kueh Hsiao Chin

Faculty of Geoinformation Science and Engineering
Universiti Teknologi Malaysia
81310 Skudai, Johor,
Malaysia.

Tel: +607-5530800 Fax: +607-5566163 E-mail: mism@fksg.utm.my

KEYWORDS: JASON-1, MODIS, sea surface current, chlorophyll-a, satellite altimetry.

Abstract:

Remote sensing satellite data is useful in chlorophyll-a concentration and sea surface current mapping applications. This paper reports on a study carried out to analyze the water circulation pattern from the generated sea surface current velocity and chlorophyll-a concentration during the monsoon seasons from remote sensing data. Merged Sea Level Anomaly (MSLA) with Orbit Error Reduction merged satellite altimetry data set is used to generate the velocity vector map by using the geostrophic velocities method over the South China Sea (SCS). The frequent MSLA data which is provided by the AVISO server twice per week is useful for sea surface current studies. The sea surface current velocity vectors are mapped in 1/3° Mercator projection. Multi-temporal Moderate Resolution Imaging Spectroradiometer (MODIS) daily data were used in the chlorophyll-a concentration mapping. The correlation between sea surface current and chlorophyll-a during the monsoon seasons is approximately 0.7-0.8 in the South China Sea. The sea surface current circulation during the north-east monsoon is anti-clockwise at the middle of SCS, however it is clockwise off the coast of Terengganu and Gulf of Thailand. For the inter-monsoon, the circulation pattern for the middle of SCS is clockwise and it is anti-clockwise off the coast of Terengganu and Gulf of Thailand. For the south-west monsoon, the circulation pattern is clockwise off the coast of Terengganu and Gulf of Thailand. However, it is approximately in a upward direction from south to north with clockwise water circulation pattern in the middle of SCS. The knowledge on sea surface current and chlorophyll-a concentration is important in fisheries and ocean science studies.

1.0 Introduction

Chlorophyll-a is a green pigment that is present in all plant life and is necessary for photosynthesis. The amount of chlorophyll-a present in water depends on the amount of algae and can also be used as an indicator of phytoplankton abundance and biomass

Paper presented at the 2nd International Hydrographic and Oceanographic Conference and Exhibition 2005 (IHOCE'05), Kuala Lumpur, 5 – 7 July 2005.

coastal waters. The concentration of chlorophyll-a also can be used as common measure of water quality. It is natural for chlorophyll-a levels to change over time. Normally, the chlorophyll concentration is higher in coastal areas than in the middle of the sea. However, some areas in the middle of the sea also have high chlorophyll concentrations and this may be caused by strong currents that bring the water with chlorophyll from the coastal areas. The monsoon winds also affect the chlorophyll distribution and upwelling brings cool, nutrient- rich water from the ocean depths to the surface allowing phytoplankton to grow (Abbott et al., 1995).

Remote sensing satellites provide large area coverage and a range of temporal scales which allow the parameters to be studied continuously. The Moderate Resolution Imaging Spectroradiometer (MODIS), first launched on the Terra satellite in December 1999 was used in the study. The relatively good resolution and daily overpasses due to wide swath make MODIS suitable for chlorophyll-a monitoring over the South China Sea.

As for sea current study, each marginal sea is unique in its characteristics which is influenced by the monsoon, climate and it's location. Conventional techniques use anchored buoys (Eulerian approach), floating buoys (Lagrangian approach), and expendable bathythermographs (XBT) or Arial XBT (AXBT) which cover limited areas (Chad Hammons, 2003). However, remote sensing satellite data provide frequent world wide data coverage and is less expensive. The use of microwave sensor will enable the data observation to be done without cloud cover problem.

The Jason-1 satellite launched in 15 September 2001 is a valuable follow-on to the high-precision, along-track ocean topography measurements provided by TOPEX/POSEIDON satellite. It ensures a smooth transition from T/P sea-level observations to the Jason series. The capability of 10 days revisit is useful for most of the ocean water observation. The payload of the satellite include the CNES Poseidon-2 Altimeter (C- and Ku- band) to measure height above sea surface and NASA Jason Microwave Radiometer (JMR) to measure water vapor along altimeter path to correct pulse delay. The sea level anomaly data were used to derive the sea surface current velocities and its circulation.

The Navy Modular Ocean Data Assimilation System (MODAS) uses historical in situ data to derive statistical relations between surface observations (dynamic height and temperature) and subsurface observations (temperature and salinity). The statistical correlation between surface and subsurface observations enable the derivation of the spatial and seasonal variations which depend on local environment and dominant oceanographic processes. A comparison between the calculated MSLA satellite altimetry and MODAS data set on the same dates have been done to validate the results.

2.0 Study area

The study was carried out in the South China Sea (Figure 1) which undergoes climate changes during the monsoon and inter-monsoon periods.

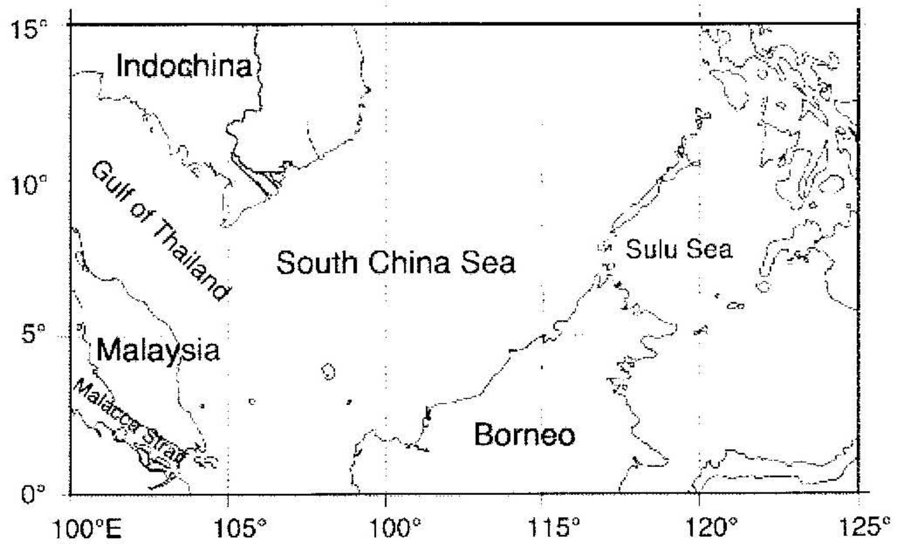

Figure 1: Geographic Extent of Study Area.

3.0 Satellite data processing

The satellite data processing involved two parts, i.e. (i) MODIS data processing for chlorophyll-a, and (ii) MSLA satellite altimetry data processing for sea surface current.

3.1 Chlorophyll-a processing

The multi- temporal level 1B MODIS data covering different dates were downloaded from GES DAAC archive for the year 2003 and 2004. The downloaded data were for different monsoon periods, which include north-east monsoon period (December - February), inter-monsoon period (March-May and September-November) and south-west monsoon period (June -August).

All the images were geometrically corrected. The data were processed to extract normalized water-leaving radiance. The chlorophyll-a concentration was estimated by using the algorithm below:

$$Chl = a\,(L_w\,551 / L_w\,443)^{b}$$

where,

Chl = chlorophyll concentration (mg m-3)
a and b = regression coefficients
Lw_{xxx} = water-leaving radiance in wavelength xxx nm

(Source: Gordon et al., 1983)

A regression analysis between measured chlorophyll concentration and water-leaving radiance from MODIS data was carried out with four in-situ data observed during satellite pass using the algorithm and the R^2 value is 0.84. The date of the MODIS data used here is the same with the in-situ data. Other algorithms were also tested in the study which gave lower R^2 values than the Gordon's algorithm. The Gordon's algorithm was used to calculate the chlorophyll concentration at three check points by using the coefficients that were obtained. Comparison of measured chlorophyll and calculated chlorophyll from MODIS data for the check points is shown in *Table 1*. The chlorophyll concentration values obtained from the Gordon's algorithm were better than the values obtained from other algorithms.

Table: 1 Comparison between measured and calculated chlorophyll-a using Gordon's algorithm.

Check Points	Measured Chlorophyll (mg/m^3)	Calculated Chlorophyll (mg/m^3)	Difference (mg/m^3)
5	0.413	0.421	0.008
6	0.428	0.453	0.025
7	0.529	0.610	0.081

Therefore instead of using four sampling points in the Gordon's algorithm, six sampling points were used in the regression analysis between measured chlorophyll concentration and water-leaving radiance with R^2 of 0.94. The derived coefficients were used to calculate chlorophyll concentration for both 2003 and 2004 images (Figures 3, 4 and 5).

3.2 Sea surface current velocity processing

The geostrophic velocities are derived from the sea level anomaly slope, with U (zonal velocity) and V (meridian velocity) combined to give velocity vectors by using the following geostrophic relation:

$$U = - g/f \{[\partial\eta/\partial y - \partial\eta_0/\partial y \exp(-y^4/L_u^4)\}$$

$$V = g/f \{\partial\eta/\partial x - \partial\eta_0/\partial x \exp(-y^4/L_v^4)\}$$

where,

f = $2\Omega \sin \phi$

Ω = angular velocity of earth's rotation
= 7.29×10^{-5} rad/sec

ϕ = latitude

η = sea surface height anomaly

∂ = delta

L_v and L_u = the area where Coriolis force become dominant.
(Source: Kaoru et. al., 1999)

The sea surface current velocity vector is obtained by using the trigonometry as shown in figure 2.

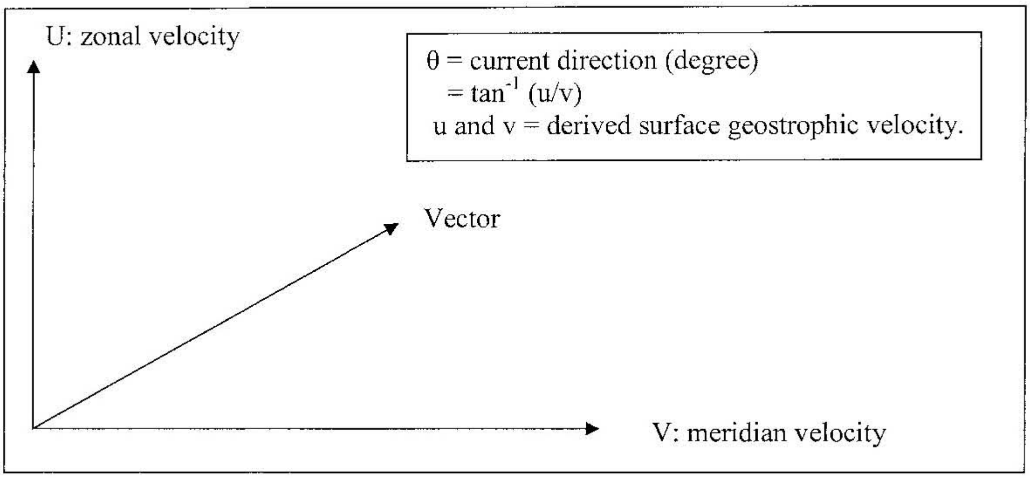

Figure 2: Trigonometry method.

The sea surface current speed is calculated using the kinetic algorithm:

$$V = (v^2 + u^2)^{0.5}$$

where,
V = speed (cm/s),
u and v = derived surface geostrophic velocity.

4.0 Results

4.1 Chlorophyll-a

The results of the processed MODIS data are shown in Figure 3 for the north-east monsoon, Figure 4 for the inter-monsoon and Figure 5 for the south-west monsoon for 2003 and 2004. Since the MODIS data have cloud cover and sunglint, those areas have been masked together with the land area (dark area in the image). The range of the calculated chlorophyll-a is between 0.1-1.2 mg/m^3 in the study area (offshore area : 0.1-0.4mg/m^3, coastal area : 0.4-1.2mg/m^3). Overall, the chlorophyll-a concentration is higher in the coastal waters and it decreases away from the coastal waters.

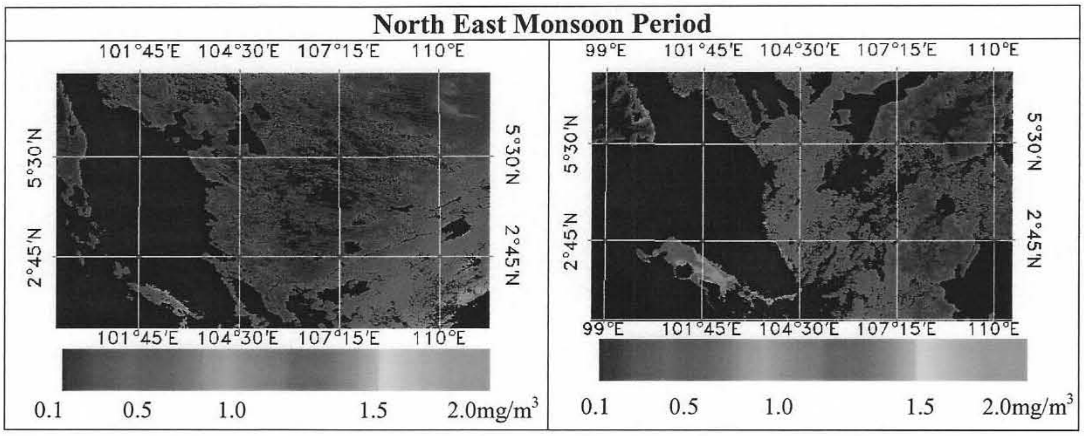

Figure 3: Distribution of Chlorophyll-a Concentration over South China Sea for 24 Jan 2003 (left) and 16 Jan 2004 (right).

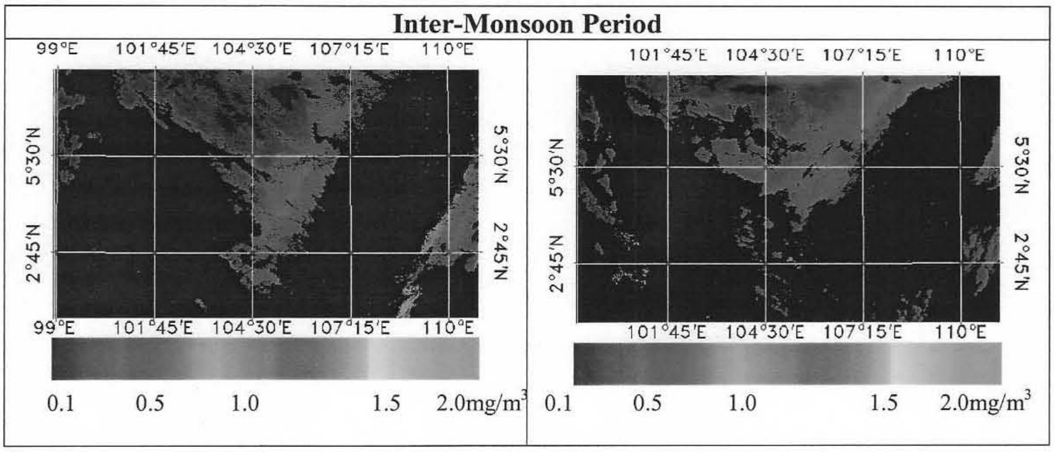

Figure 4: Distribution of Chlorophyll-a Concentration over South China Sea for 20 Mar 2003 (left) and 22 Mar 2004 (right).

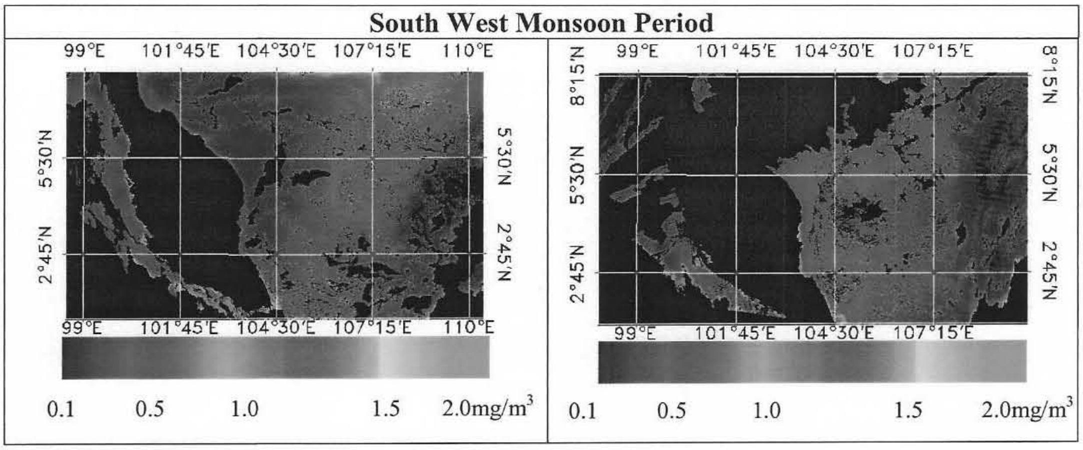

Figure 5: Distribution of Chlorophyll-a Concentration over South China Sea for 8 June 2003 (left) and 17 June 2004 (right).

4.2 Sea Surface Current

The sea surface current velocity calculated from the MSLA satellite altimetry data set were compared with the MODAS data set for each monsoon seasons (Fox et al., 2001). The general pattern produced by MSLA data set is nearly the same with the current pattern produced by the MODAS data set. Some apparent differences that are noticeable are due to the mapping interval used, where the MODAS uses 1° grid interval and MSLA use 1/3° grid interval. The results are shown in Figures 6, 7 and 8.

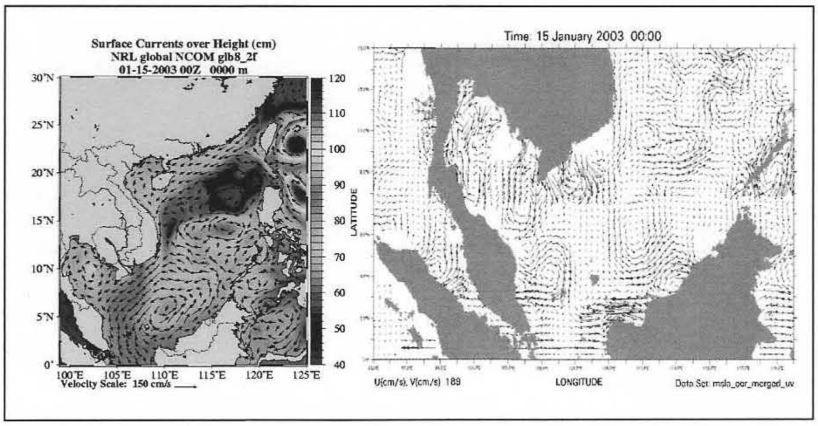

Figure 6a: Sea Surface Current from MODAS and MSLA data during North East Monsoon (15 Jan 2003).

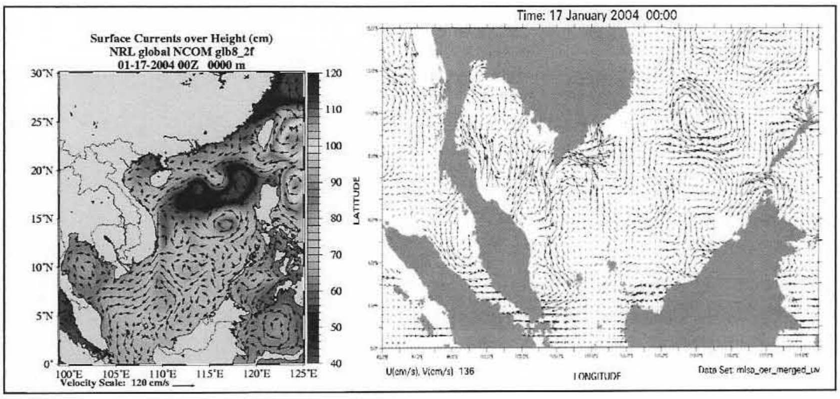

Figure 6b: Sea Surface Current from MODAS and MSLA data during North East Monsoon (17 Jan 2004).

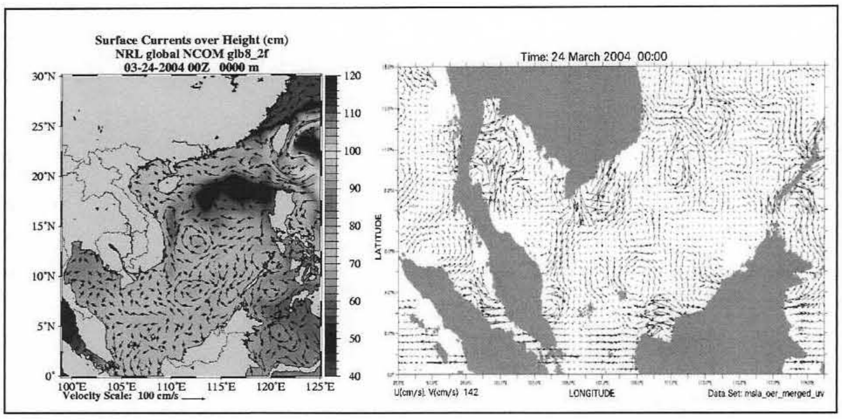

Figure 7a: Sea Surface Current from MODAS and MSLA data during Inter Monsoon (19 Mac 2003).

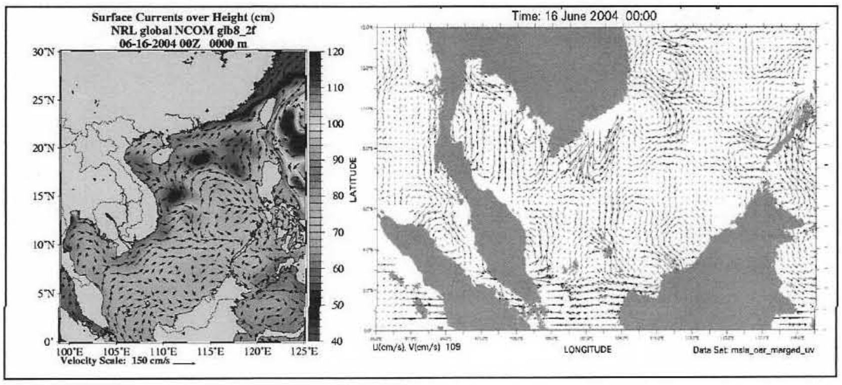

Figure 7b: Sea Surface Current from MODAS and MSLA data during Inter Monsoon (24 Mac 2004).

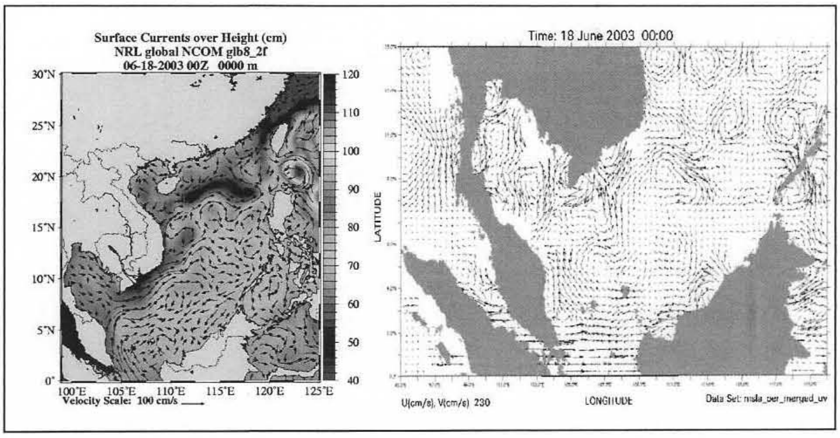

Figure 8a: Sea Surface Current from MODAS and MSLA data during South West Monsoon (18 Jun 2003).

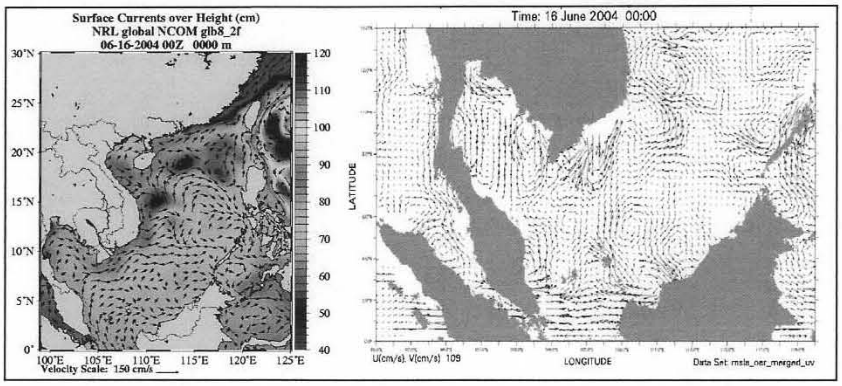

Figure 8b: Sea Surface Current from MODAS and MSLA data during South West Monsoon (16 Jun 2004).

4.3 Correlation between chlorophyll-a and sea surface current velocity

The correlation between chlorophyll-a and sea surface current velocity were analyzed by using logarithmic relationship. The correlation obtained is 0.7-0.8 (Figures 9, 10 and 11). The results show that there is good correlation between chlorophyll-a and sea surface current velocity. When the sea surface current velocity is low, there is an increase in the chlorophyll-a concentration.

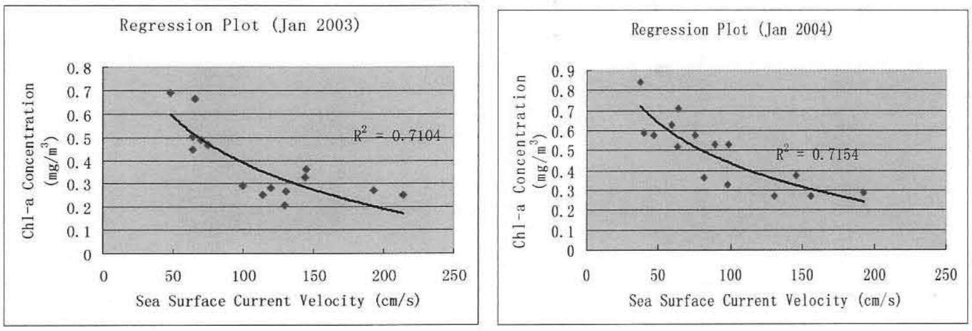

Figure 9: Chlorophyll-a Versus Sea Surface Current Velocity (North-East Monsoon).

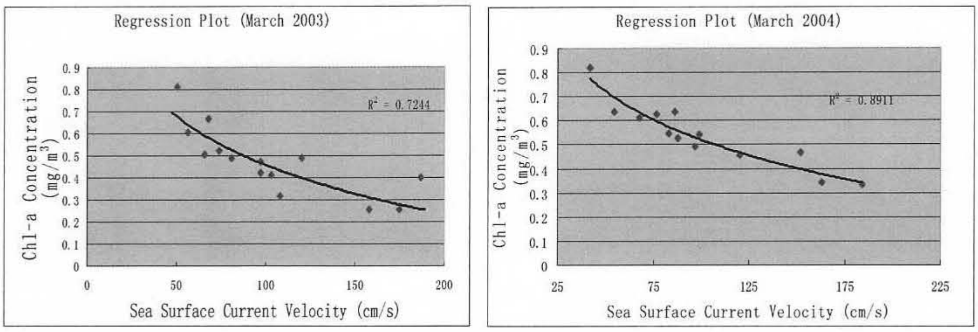

Figure 10: Chlorophyll-a Versus Sea Surface Current Velocity (Inter-Monsoon).

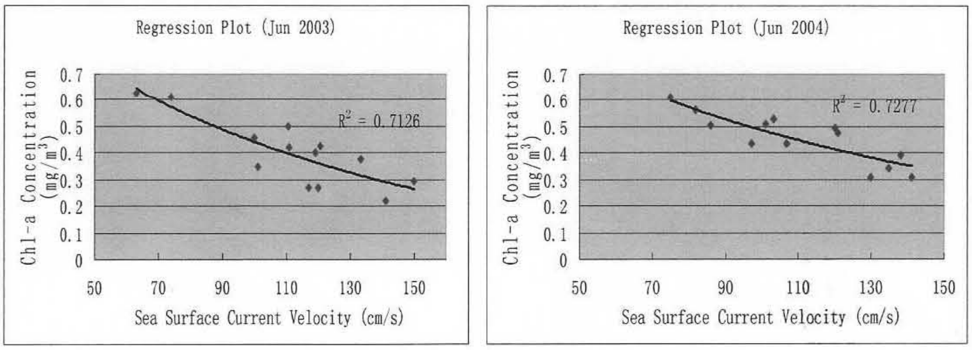

Figure 11: Chlorophyll-a Versus Sea Surface Current Velocity (South-West Monsoon).

5.0 Conclusions

The chlorophyll-a concentration study shows that chlorophyll-a is higher at the coastal waters (0.4-1.2mg/m^3) and decreases away from the coastal waters (0.1-0.4mg/m^3). The correlation between sea surface current and chlorophyll-a during the monsoon seasons is approximately 0.7-0.8 in the South China Sea. When the sea surface current velocity is low, there is an increase in the chlorophyll-a concentration. The sea surface current circulation during the north-east monsoon is anti-clockwise at the middle of SCS, however it is clockwise off the coast of Terengganu and Gulf of Thailand. For the inter-monsoon, the circulation pattern for the middle of SCS is clockwise and it is anti-clockwise off the coast of Terengganu and Gulf of Thailand. For the south-west monsoon, the circulation pattern is clockwise off the coast of Terengganu and Gulf of Thailand. However, it is approximately in a upward direction from south to north with clockwise water circulation pattern in the middle of SCS.

Acknowledgements

We would like to thank Prof. T. Yanagi of Kyushu University, Japan and the Japan Society for Promotion of Science (JSPS) for making this study possible.

References

Abbott, M.R., and B. Barksdale (1995). "Variability in Upwelling Systems as Observed by Satellite Remote Sensing." Upwelling in the Ocean: Modern Processes and Ancient Records, Berlin, pp.221-238.

Chad Hammons ASEN (2003). "Using Satellite Altimetry to Detect Ocean Current". Aviso-Altimetry - Newsletter 9.

Kaoru Ichikawa and Shiro Imawaki (1999). "Area Dependency of Estimation Errors in Geostrophic Velocity", Research Institute for Applied Mechanics, Kyushu University, Japan.

Fox, D.N., W.J. Teague and C.N. Barron (2001). "The Modular Ocean Data Assimilation System (MODAS)", Journal of Atmospheric and Oceanic Technology, Vol 19, pp 240-252.
http://www7320.nrlssc.navy.mil/modas/modas_jaot.pdf

Gordon, H. R., Clark, D. K., Brown, J. W., Brown, O. B., Evans, R. H., and Broenkow, W. W., (1983). Phytoplankton pigment concentrations in the Middle Atlantic Bight: comparison of ship determination and CZCS estimates. Applied Optics, 22, 20–36.